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EXAMINNING THE EFFECTS OF LAND USE ZONING ON LAND PRICE WITH GEOGRAPHICALLY WEIGHTED REGRESSION

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Abstract The effects of land use zoning on land price is expected to vary across places within an metropolitan area. To assess the local effect of a land use zone in each place, hedonic equation of land prices is estimated using geographically weighted regression (GWR) that allows estimation of locally varying but spatially continuous parameters. An experiment for Sendai Metropolitan Area (Miyagi, Japan) reveals that the effects of land use zones indeed vary, and in some locations even the more restrictive zone designation raise the price of that land than designated otherwise. Based on the equation, the zone that maximizes the price of land for each location can also be identified. While GWR seem to be a usefull tool in evaluating and designing urban land use planning, the experiment in this paper also reveals that obtaining robust result is difficult, and further research is necessary to specify variables and fuctional forms for reliable estimates.

Key words: urban planning, land use zoning, land price, geographically weighted regression

1. Introduction

How does a land use zone designation to a lot affect the price of that lot? Which land use zoning maximizes the land price of a lot in a particular place within a metropolitan area? These are the questions to be asked in this paper. Measuring the effects of land use zoning on land price in a hedonic pricing framework is difficult because the effects are expected to vary across places.

Assume a monocentric city with all employment at CBD, with apartment builders and prospective home owners bidding for land. Considering only the commuting cost *alla* Alonso, we expect bid-rent curves to decline as distances to CBD increase, and the rent gradient to be steeper for apartment builders because of higher density that materialize from high-rise buildings. The market allocates lands to the highest bidder and the land price will follow the envelope of the constituent bid-rent curves (Wallace 1988); through the points ABC in Fig. 1. The competition at the market would also lead to natural separation of apartments and single family homes. Now introduce land use zoning prohibiting apartments beyond location d_1 (Fig. 1). Then, the land price will follow through the points ADC as apartment builders withdraw from the market beyond location d_1. The land use zoning lowers the land price at varying degree between d_1 and d^*. Alternatively, if a land use zoning prohibits apartments beyond location d_2 but allowing single family homes within d_2, the resulting land price would follow the points ABC, making no effect on land price.

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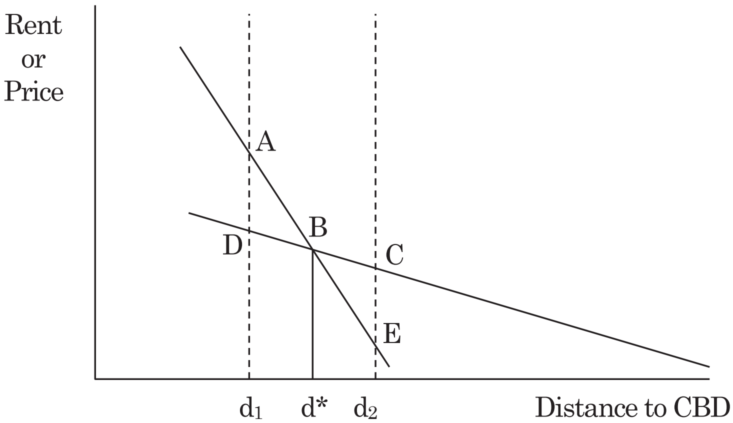


Fig. 1 Bid rent curves and the effects of zoning

Theoretical consideration so far suggest that land use zoning at best does not affect land price, otherwise lowers the price differently across locations. However, land use zoning can have positive effect on land price if the zoning mitigates negative externalities arising from undesirable land use mix (Grieson and White 1981). With negative externalities, the land price without land use zoning will be lower than that expected from the envelopes of consitutent bid-rend curves, and with the appropriate zoning boundary at location d* would maximizes the land price in all locations if the land use zoning removes negative externalities. This latter consideration suggests that the effect of land use zoning is conditional on prevailing land uses; if a zone succeeds in avoiding undesirable land use mix, the zone will have positive effect on land price. Therefore, the effects of land use zoning are expected to vary across locations. In a monocentric city, variation in the effects of land use zoning is expected to have a concentric pattern.

There have been several attempts to fit locally varying regression equations to metropolitan land price, to obtain land price surface (Colwell and Munneke 2003), and to improve accuracy of the predicted price (Uesugi 2012), but this paper does the same specifically to assess the local effects of land use zoning.

2. Method and Materials

This paper uses geographically weighted regression (GWR) to measure locally varying effects of land use zones on land price. GWR estimates local regression parameters for each location by weighting the samples according to the distances to that location, and repeating the estimation for all locations (Fotheringham *et al*. 2002). GWR assumes that regression parameters differ by locations, but they vary continuously over space. In our case, parameters are expected to differ because land use zones may not be in accordance with market demand and their effects is conditional on prevailing land uses, but they vary continuously because proximate lots are close substitutes. The spatial resolution of varying parameters would depend on the density of sample points, however. GWR can be implemented with GWR4 software developed by the GWR4 Development Team (Nakaya 2014).

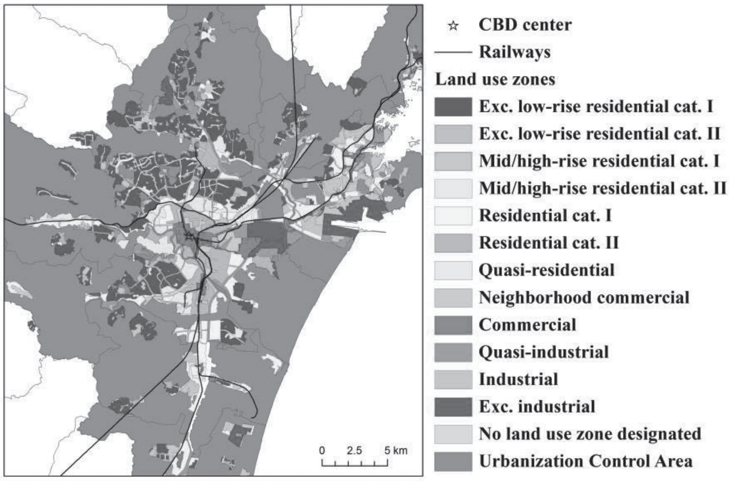


Fig. 2 Land use zoning in Sendai Metropolitan Area. Source: National Land Numerical Information.

Japanese urban planning divide an urban area and its surroundings into urbanization control areas and urbanization promotion areas, and the latter are further divided into 12 land use zones (and a zone undesignated area), and density zones through specification of floor to area ratio (FAR) and building coverage ratio (BCR). The land use zoning is oriented towards reserving good residential areas for single family homes. 'Excusively low housing residential category I' is the most restrictive zone where only low density housing can be built, whereas 'commercial' zone allows almost any types of buildings except factories, with the latter allowed in the three industrial zones. The specification for each land use zones can be found in MLIT (2003).

Sendai Metropolitan Area is chosen for the experiment. The city is a regional center of Tohoku Region at about 300 km north of Tokyo, which have expanded rapidly during the 1970s-1980s, and currently having a stable metropolitan population of about a million. The city can be largely approximated as monocentric city and offers an ideal test case for this study (Fig. 2).

Land price data for January 2014 is obtained from "Publication of Land Price" and "Prefectural Land Price Research" datasets provided by the Ministry of Land, Infrastructure and Transport and Tourism. The two datasets record land prices of sample locations appraised by licensed real estate appraisers in a similar format. Since the survey date of "Prefectural Land Price Research" is July whereas that of "Publication of Land Price" is January, land prices as of January for sample locations in the former are estimated by averaging the land prices as of July of the year and a year before. The analysis uses 577 sample locations within Sendai Metropolitan Area as defined in 2005 version of Urban Employment Areas (Kanemoto and Tokuoka 2002). The dependent variable is the natural log of land price, expecting that land prices fall exponentially with the increase in the distance from the CBD (Anas *et al.* 1998). Most independent variables are available or can be derived from the two land price datasets, such as distance to the nearest station, lot size, lot shape, the width of adjacent road and current land use, in addition to land use zones, BCR and FAR. Additionally, 500m Mesh Employment data from Economic Census 2009 is used to determine the CBD center, by finding the maximum of local employment density, and then distances to the CBD center were measured. The

Table 1 Regression results on natural logarithm of land price

Variables	Model1 Global Coefficients			Model2 Local Coefficients			Model3 Local Coefficients	
	Estimate	Standard Error		Mean	STD	Spatial variability test	Mean	STD
Intercept	10.526	0.348	**	10.147	0.456	-102.69	9.829	0.596
Employment 0-0.5km (000s)	0.017	0.005	**	-	-	-	-	-
Employment 0.5-1km (000s)	0.007	0.003	*	-	-	-	-	-
Employment 1-2km (000s)	0.002	0.001	**	-	-	-	-	-
Employment 2-4km (000s)	0.001	0.001		-	-	-	-	-
Employment 4-8km (000s)	0.001	0.000	*	-	-	-	-	-
Employment 8-16km (000s)	0.000	0.000		-	-	-	-	-
Employment 16-32km (000s)	0.000	0.000		-	-	-	-	-
Employment potential (persons・m^{-1})				0.005	0.000	-18.29	0.005	0.001
Distance to CBD (km)	-0.023	0.008	**	0.005	0.031	-16.35	0.007	0.035
Distance to nearest station (km)	-0.023	0.004	**	-0.042	0.015	-15.43	-0.043	0.015
Exc. low-rise residential cat. I (binary) †	0.000	-		0.000	-	-	0.000	-
Exc. low-rise residential cat. II (binary)	0.220	0.132		0.021	0.197	1.55	0.212	0.233
Mid/high-rise residential cat. I (binary)	-0.028	0.105		-0.181	0.175	0.69	0.060	0.173
Mid/high-rise residential cat. II (binary)	-0.038	0.091		-0.108	0.058	-0.81	0.134	0.206
Residential cat. I (binary)	-0.012	0.084		-0.091	0.068	0.50	0.152	0.219
Residential cat. II (binary)	0.095	0.085		0.010	0.049	-12.33	0.250	0.223
Quasi-residential (binary)	-0.073	0.175		-0.067	0.117	1.63	0.177	0.233
Neighborhood commercial (binary)	0.031	0.192		-0.004	0.185	-31.76	-0.777	1.413
Commercial (binary)	-0.314	0.217		-0.402	0.188	-3.52	-0.915	1.418
Quasi-industrial (binary)	-0.421	0.119	**	-0.486	0.169	-0.37	-0.237	0.280
Industrial (binary)	-0.064	0.228		-0.317	0.231	0.13	-0.088	0.293
Exc. industrial zone (binary)	0.023	0.245		0.299	0.686	-16.19	0.516	0.666
Land use zone undesignated (binary)	-0.175	0.145		-0.198	0.575	1.50	-0.407	0.504
Urbanization Control Area (binary)	-0.705	0.117	**	-0.521	0.174	-1.00	-0.743	0.225
Fire mitigation zone (binary)	-0.112	0.102		-0.050	0.031	-0.40	0.016	0.037
Quasi-fire mitigation zone (binary)	0.058	0.045		0.053	0.051	-7.21	0.050	0.049
BCR (%)	-0.018	0.005	**	-0.022	0.007	0.22	0.024	0.036
BCR squared	-	-		-	-	-	0.001	0.001
FAR (%)	0.003	0.000	**	0.004	0.000	0.85	0.000	0.001
FAR squared	-	-		-	-	-	0.000	0.000
Gas provided (binary)	0.057	0.045		0.131	0.058	0.00	0.132	0.059
Sewage provided (binary)	0.064	0.090		0.252	0.301	-10.01	0.307	0.538
Lot size (are)	0.000	0.000		0.006	0.008	-10.87	0.006	0.008
Lot shape (width to depth) (%)	0.000	0.000		0.000	0.000	2.35	0.000	0.000
Front road witdh (m)	0.013	0.002	**	0.012	0.001	0.19	0.012	0.001
Current use - Residential (binary) †	0.000	-		0.000	-	-	0.000	-
Current use - Commercial (binary)	0.091	0.082		0.051	0.097	-5.77	0.054	0.096
Current use - Industrial (binary)	-0.862	0.212	**	-1.199	0.796	-9.62	-1.169	0.769
Diagnostics for Global Regression								
AICc	171.604			184.350			182.607	
R square	0.917			0.913			0.914	
Adjusted R square	0.912			0.908			0.909	
Diagnostics for Local Regression								
Bandwidth	100			100			100	
AICc	66.423			104.573			104.925	
R square	0.944			0.937			0.938	
Adjusted R square	0.931			0.925			0.925	
N	577			577			577	

*,** Statistical significant at 5% and 1%, respectively.
† Reference category

same data is used to measure the local employment availability, by calculating the number of employment in several annuli from each sample point.

3. Result

The GWR results on land price are shown in three models in Table 1. Model 1 examines the effect of accessibility to employment measured by employment annuli of various distances from each location, and only global coefficients (i.e., constants as in the usual regression) are reported. The result suggests that the effect of employment declines closely to inverse of distance, so 'employment potential' is defined as follows and used in the subsequent models.

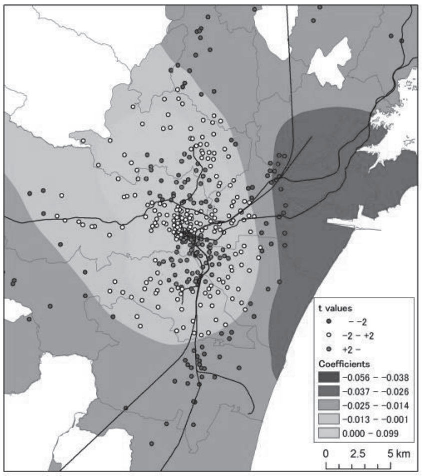
$$\sum_i \left(N_i / r_i\right)$$

where N_i is employment of an annulus (persons) and r_i is the representative distance (meters) of the annulus.

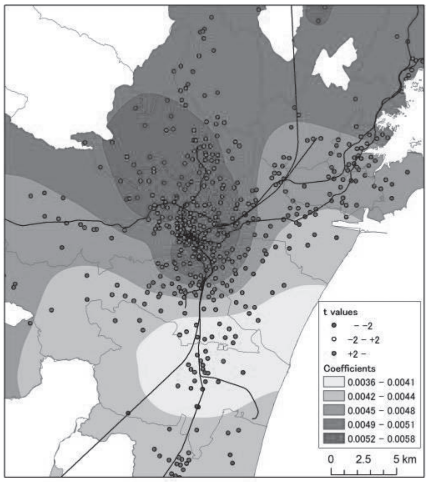
Model 2 performs local regression with adaptive Gaussian weight using the distance of the nearest 100th sample point as the standard distance. Employment of various annuli are removed as adjacent annuli are strongly correlated and pose substantial difficulty in interpreting the result, and replaced by employment potential defined above. Distance to CBD, which is also a measure of accessibility to employment, is retained however as it seemed to improve the model fit substantially. The result shows that AICc decline substantially by assumming geographically varying parameters (as indicated by global and local regression diagnostics) and R-squared of 0.937 is obtained. Spatial variability tests that compare changes in AICc by switching coefficients from a fixed one to geographically varying one for each dependent variable suggest that coefficients for some of the land use zones varies spatially, as well as those for intercept, employment potential, distance to CBD, and distance to nearest station. Spatially varying coefficients for selected variables are shown in Fig. 3. For 'distance to CBD', we also find significantly positive coefficients in near the city center (i.e., higher price away from CBD center), but this is probably because of greater coefficients for 'employment potential' in the same area (Figs. 3a and 3b). If a pattern of coefficients is similar to the dependent variable itself, as in the case of 'distance to CBD' or 'employment potential' to a lesser extent, the functional form may need to be reconsidered. The intercept represents that of 'exclusively low-rise residential category I', our reference category, and shows an expected pattern of low in the city center and high in the suburbs (Fig. 3c). However, very similar patterns of coefficients between the intercept and 'distance to CBD' suggest some problem with colinearity that arise because 'exclusively low-rise residential category I' is designated only in places away from the CBD. It is interesting that 'commercial' zone have significantly negative effect near Nagamachi area, a sub center in Sendai City where 'commercial' zone is designated (Fig. 3d). The only explanation that a lax regulation such as 'commercial' zone has negative effect on land price is that it is allowing undesirable land use mix.

Figure 4a shows the land use zone that maximize land price, by identifying the land use zone that have the largest coefficient in Model 2. 'Neighborhood commercial' zone appear at the CBD, and relatively lax residential zones of 'residential catetogry I' and 'quasi-residential' zones appear adjacent to CBD. The more restrictive residential zones of 'exclusively low-rise residential category I' and 'exclusively low-rise residential category II' zones also appear in the suburbs. The figure also indicates the statistical significance of difference in coefficients between the actual zoning and the maximizing zoning, which shows that price change from applying alternative zone are insignificant in most places, however. Noticible siginificant changes occur in cases where ‘urbanization control zones’ (where developments are prohibited) are changed to ‘exclusively low-rise residential category II’ zone, which is not at all surprising.

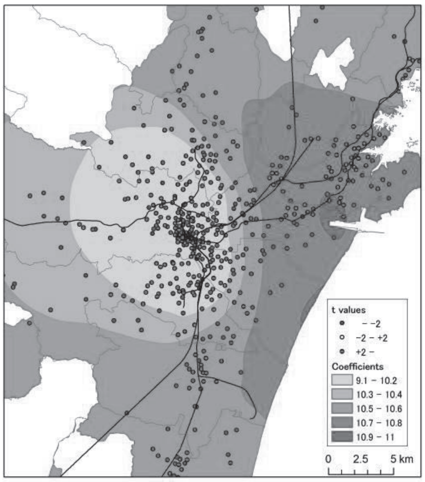
The result was far from robust, however, and a small change in included variables yielded substantially different result. For example, Model 3 included quadrant terms for FAR and BCR in the hope to examine the levels of FAR and BCR that maximize land price (see Table 1). Then, the land price maximizing zones changed substantially (Fig. 4b) with ‘exclusively low-rise residential category I’ zone appearing at CBD. The coefficients for quadrant terms of FAR and BCR were positive in most locations so it was not possible to identify land price maximizing FAR and BCR.



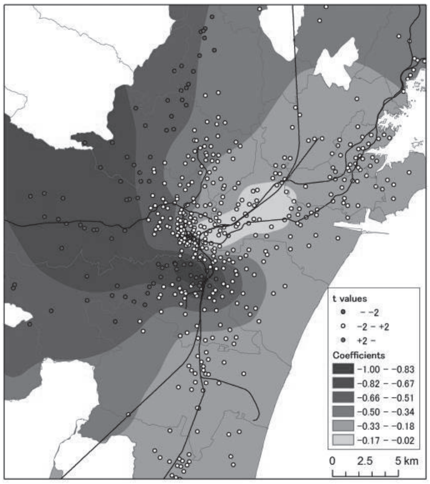
(a) Distance to CBD



(b) Employment potential

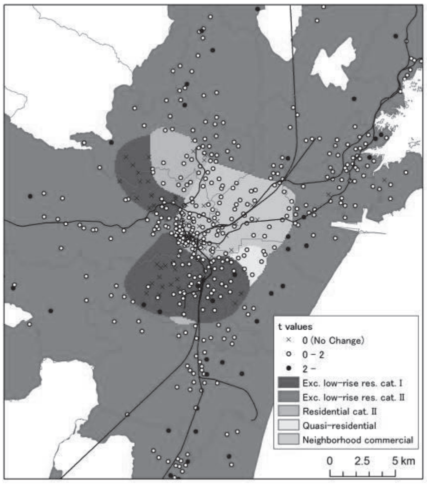


(c) Intercept

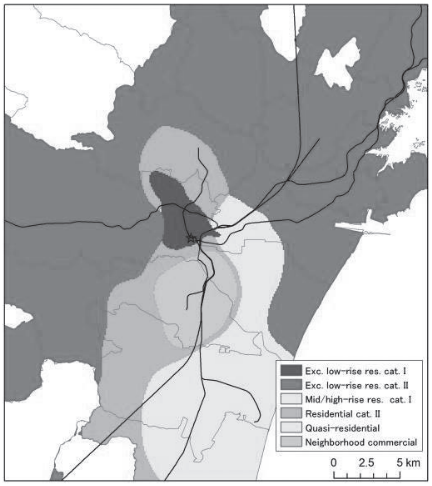


(d) Commercial

Fig. 3 Selected coefficients for model 2



(a) Model 2



(b) Model 3

Fig. 4 Land price maximizing land use zones

4. Conclusion

Fitting local regression to land price is analogous to a real estate appraiser evaluating a land price of a place based on land prices of similar places nearby, adjusting for small differences in location, land use zone and other individual properties. The adjustments for the differences are quantified in terms of coefficients in the regression. Therefore, it is not surprising that local regession yields superior prediction to global regression. However, the approach has several difficulties as well. First, if there are no alternative land use zones nearby, then it will not be possible to estimate the effect of the land use zone accurately. In our experiment, we could not distinguish whether t-values are close to zero because the land use zone has negligible effect, or because there were not enough alternative land use zones nearby. Second, problems arising from multicolinearity among independent variables may be exacerbated in local regression because of fewer effective numbers of samples or less diversity within the analysis window. Finally, the very flexibility that local regression offers makes it more difficult to find interpretable model.

Despite such difficulties, GWR seem to be a useful tool in evaluating and designing urban planning because of its ability to take account different roles that each location within a metropolitan area has. Put more generally, GWR would be useful in cases where different regulations are applied to places. That is because if each regulation have the same effect to all places and a particular regulation always leads to the best result, then it is not possible to justify different regulations to places. If a policy that applies different regulations to places is good and supported, then each regulation should have different effects across places.

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